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Dielectric and Magnetodielectric Properties of the Magnetic Fluids

Streszczenie. (Dielektryczne i magnetodielektryczne właściwości płynów magnetycznych). *W artykule opisano charakterystyczne własności dielektryczne i magnetodielektryczne cieczy magnetycznych. Określono własności cieczy magnetycznych w polu przemiennym o częstotliwości 50 Hz. Wykonano pomiary w polach kombinowanych elektrycznych i magnetycznych: równoległych (**E** ∥ **B**), prostopadłych (**E** ⊥ **B**) oraz przy braku pola magnetycznego (**B** = 0). Analizę tych własności wykonano dla cieczy magnetycznych na bazie inhibitowanego oleju transformatorowego ITO 100 z objętościowa koncentracją cząsteczek magnetytu w zakresie od 0.185 % do 3.214 %.*

Abstract. *There are described characteristic dielectric and magnetodielectric properties of the magnetic fluids in this contribution. The behaviour of the magnetic fluids in the AC electric field with frequency f = 50 Hz is defined. Measurements were carried out in the combined electric and magnetic fields, when fields were parallel (**E** ∥ **B**), perpendicular (**E** ⊥ **B**) and without the presence of the magnetic field (**B** = 0). Analysis of these properties were done for the magnetic fluids based on the inhibited transformer oil ITO 100 with volume concentrations of the magnetite particles ($FeO.Fe_2O_3$) in range from 0.185 % up to 3.214% .*

Słowa kluczowe: ciecz magnetyczna, pola elektryczne i magnetyczne, anizotropia magnetodielektryczna, stabilność elektryczna, współczynnik strat
Keywords: magnetic fluid, magnetic and electric fields, magnetodielectric anisotropy, electric stability, loss parameter

Introduction

Investigation of the dielectric and magnetodielectric properties of the magnetic fluids is connected intimately with the magnetodielectric effect that is indicated by the magnetodielectric anisotropy [3]. The investigation results of the electric stability of the magnetic fluids with various volume concentrations of the fine magnetite particles (0.125% - 4%) at two orientations of the electric and magnetic fields (**E** ∥ **H**, **E** ⊥ **H**) showed also the magneto-dielectric anisotropy that causes fair-sized difference in the electric stability of the magnetic fluids dependent on the orientation of the electric and magnetic fields. Relative permittivity (ε_r) that was one of the important observed quantities is dependent on the applied magnetic and electric fields and their mutual orientation.

The magnetic fluids in an alternating electric field at presence of the magnetic field

There were observed processes in the macroscopic surroundings of the electrode system and in the microscopic surroundings between the magnetic particles theirselves and the needle-shape aggregates (clusters) made of magnetite particles. One of the possible solutions of these processes is equation that expresses effect of force action of magnetic and electric fields in surroundings.

The force causing mobility of the particle clusters in the electric field is dependent on their weight that is dependent on both volume concentration of the magnetite particles and local density of the magnetic fluids. Stokes force, that expresses effect of the dynamic viscosity of the magnetic fluids, is not negligible at application of the alternating electric field with frequency 50 Hz. Velocity of the particles **v** and orientation of its components (($\mathbf{v}_{\|}$, resp. $\mathbf{v}_{\perp}$) relative to vector **E**, pertinently to vector **B** have important role from point of view of the magnetic field action with induction **B**.

It can be suggested the solution of the following cases:

a) If **E** is variable and **B** = 0 T, then force in the electric field has as a consequence the mechanical stress (compressively, tensile) in the magnetic fluids. If we accept the hypothesis about local differential changes of the permittivity and density caused by action of the strong electric field then a volume force exists due to the heterogeneous field and anisotropy of the insulator medium. Investigation of the origin and existence of space charge between the electrodes shows [5] that action of the electric field causes polarization of the magnetic fluid components in nanometric range. As a consequence of this process is gradient force that affects polarized particles.

b) Simultaneous influence of the electric and magnetic fluid on the magnetodielectric properties of the magnetic fluids is devoted to analyse cases that show what application of electric and magnetic field will be dominated for determination of magnetic fluids permittivity and their loss parameter at respect of the observed medium anisotropy. It has been observed cases when vectors **E** and **B** were parallel and perpendicular (**E**||**B**, **E**⊥**B**). That is why divide particles velocity **v** and intensity of electric field **E** into components parallel and perpendicular to magnetic induction **B** ($\mathbf{v} = \mathbf{v}_{\|} + \mathbf{v}_{\perp}$ and $\mathbf{E} = \mathbf{E}_{\|} + \mathbf{E}_{\perp}$). It can be showed that charged particles motion in the case **E**⊥**B** is characterized by two types of motion: drift with constant velocity $\mathbf{v}_\mathbf{E}$ and circle motion with velocity $\mathbf{v}_{\perp}'$ that is caused only by magnetic field. If $\mathbf{v}_\mathbf{E}$ exists, then particles move in perpendicular direction to vectors **E** and **B** in combined electric and magnetic fields that causes particles motion on a spiral.

Magnetodielectric properties of the magnetic fluids and their anisotropy parameter

The anisotropy parameter ($g(B)$) of magnetodielectric effect is defined in [1] and [3] by equation:

$$g(B) = -\frac{\varepsilon_{\|}(B) - \varepsilon(0)}{\varepsilon_{\perp}(B) - \varepsilon(0)}, \quad (1)$$

where $\varepsilon_{\|}(B)$ and $\varepsilon_{\perp}(B)$ are permittivity for **E**||**B** and **E**⊥**B**, and $\varepsilon(0)$ for **B**=0. Investigation of magnetic fluids electric stability at DC high voltage confirmed anisotropy (Fig.1).

Investigation of magnetodielectric properties of magnetic fluids was devoted to observe dependencies relative permittivity on magnetic fluid volume concentration and on value of applied voltage in region of weak electric fields up to $2.5 \cdot 10^6$ V/m. There was observed dielectric losses simultaneously in magnetic fluids in dependence on size of applied electric voltage and volume concentration of magnetic fluid. Relative permittivity changes of magnetic fluid at low magnetic fluid concentration (0.185%) in dependence on voltage (0.5kV - 2 kV) reach low values. Dependence $\varepsilon_r = f(U)$ is non linear at higher magnetic particles volume concentrations (Fig. 2).

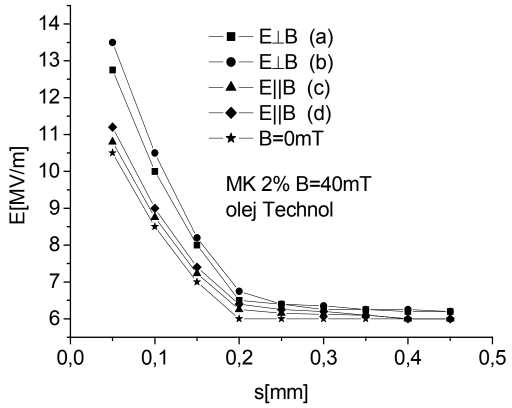

Fig.1. The electric stability of magnetic fluid at different orientation ***E*** and ***B*** (b-opposite orientation to case a, c-parallel orientation, d- antiparallel orientation).

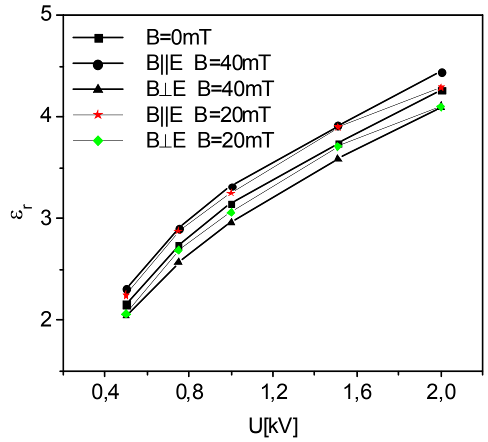

Fig.2. Dependence of ε_r on applied voltage at different orientation ***B*** and ***E***

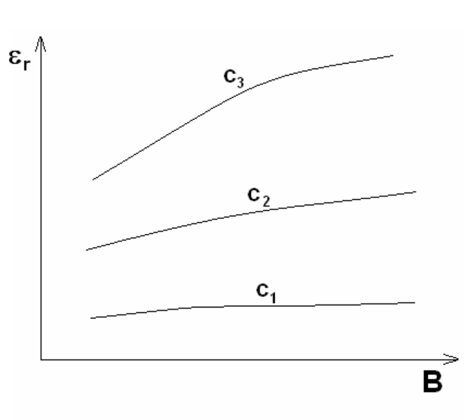

Fig.3: Influence of magnetic field on change of ε_r at three concentrations ($c_1<c_2<c_3$)

Values of ε_r at ***E***||***B*** and ***E***⊥***B***, and for ***B***=0 refer to anisotropy degree in magnetic fluids distinctly. Relative permittivity quantity increases with the increase of magnetic fluid concentration. Both the increase of liquid medium polarizability and extending of needle like clusters and their higher volume concentration cause it.

The generalizing relative permittivity course in dependence on applied magnetic field has analogous nature, when concentration of magnetic fluid is as a parameter (Fig. 3). Relative permittivity increase does not correspond to linear increase of observed liquid volume concentration.

Dielectric losses in the magnetic fluid are defined by dielectric loss parameter tgδ. The model of the situation in the magnetic fluid at acting of electric field is showed in the Fig. 4a. The influence of low magnetic particles concentration on dielectric losses development was demonstrated clearly (Fig. 4b). Slow turn of dielectric losses mechanisms at increasing of magnetic fluids concentration causes space charge mobilizing, mainly at the increase of voltage. By application of complex permittivity and conductivity on solution of situation in composite system (components are: transformer oil, oleic acid, magnetic particles Fe_3O_4) it can be expressed prediction that space charge of system increases at voltage increase and it is not be able to follow changes of electric field at frequency f = 50 Hz because of by both its volume inertia and lower mobility between electrodes space. As a consequence loss parameter tgδ decreases in dependence on voltage and its value is several times higher than at original low concentration (Fig. 5).

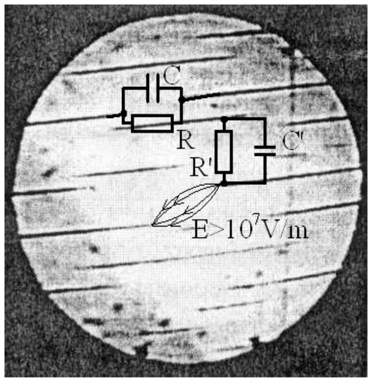

Fig.4a. Model of the situation in the magnetic fluid with concentration Φ = 0.185%

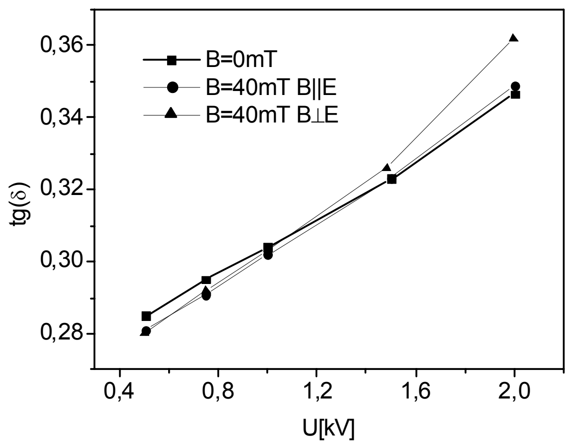

Fig. 4b. Dependence of loss parameter on voltage at Φ = 0.185%

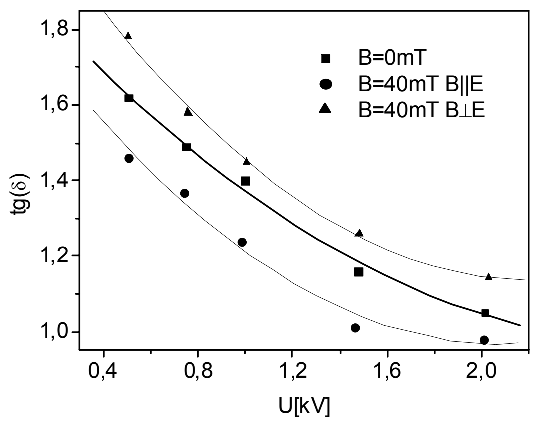

Fig.5. Dependence of loss parameter on voltage at Φ = 3.214%

Dependence of relative permittivity on volume influence of intensity of electric field ***E*** at concentration of the magnetic fluid was observed in region of weak fields. Dominant two field orientations (***E***||***B*** opposite to ***E***⊥***B***) for relative permittivity were observed (Fig.6). The anisotropy degree of magnetic fluid in dependence on voltage is shown in the Fig. 7.

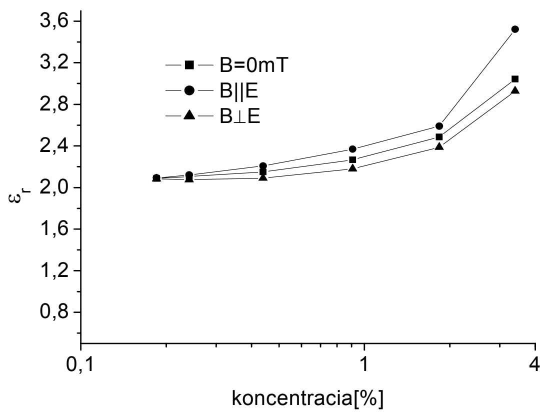

Fig.6. Dependence of ε_r on magnetic fluid concentration

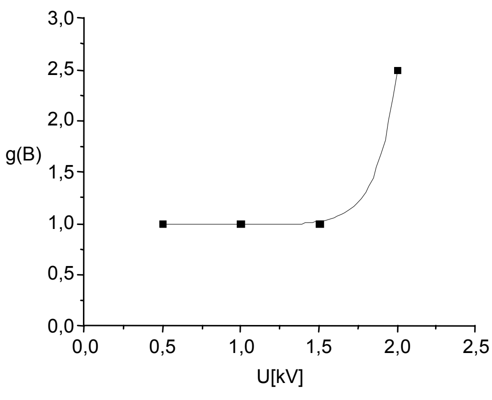

Fig.7. Dependence of magnetodielectric anisotropy parameter on voltage

Conclusions

This work is contribution to study of magnetodielectric properties of liquid systems containing fine mono domain magnetic particles (Fe_3O_4) of nanometric size. Investigation was realized in combined electric and magnetic fields, when orientation of applied fields was ***E***||***B***, ***E***⊥***B*** and ***E*** was variable at ***B*** = 0 T. Magnetodielectric anisotropy was proved by experiments in this kind of materials. The alternating voltage was chosen for experiments because of possibility to use magnetic fluids in power transformers.

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REFERENCES

[1] Espurz A., Alameda J.M., *J. Phys.D: Appl.Phys*. 22 (1989), 1174
[2] Mailfert A.J., Nahounou B., Dielectric behaviour of a ferrofluid subjected to a uniform magnetic field. In: *IEEE Trans.Magn.*16 (1980) 254.
[3] Tomčo L.: *Thesis*, UPJŠ Košice 2000.
[4] Marton K., Tomčo L., Kopčanský P., Herchl F., Timko M., Koneracká M., The development of electric breakdown in magnetic fluids in combined magnetic and electric fields, *Przeglad Elektrotechniczny- Konferencje,* no. 1/2005, p. 161
[5] Marton K., Tomčo L., Herchl F., Kopčanský P., Dolník B., Timko M., Koneracká M.: Space charges in magnetic fluids at creating of breakdown channel. In: *Proc. DISEE 2006*, 16
[6] Kúdelčík J., Gutten M., Brandz M.: Development of electrical breakdown in transformer oil. *Advances in Electrical end Electronic Eng*. 5 (2006) 277
[7] Marton K., Volume forces classification contributing to degradation of polymer isolation, *Ekt.* 53 (2000) 92, č.3

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